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Herbicide and Conifer Options for Reforesting Upper Slopes in the Cascade Range

Edward J. Dimock II

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Author

EDWARD J. DIMOCK II is principal silviculturist, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, Oregon 97331.

Abstract

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Nine herbicides were compared for aiding establishment of four conifer species on upper-slope forest sites dominated by sedge and beargrass. Both glyphosate and a mixture of atrazine + dalapon produced substantial and consistent gains in survival of all four conifers after 3 years.

Keywords: Herbicides (-regeneration, site preparation (-regeneration, herbicide formulations, regeneration (stands), western white pine, Engelmann spruce, noble fir, Shasta red fir.

Summary

Nine herbicides (asulam, atrazine, bromacil, cyanazine, dalapon, glyphosate, hexazinone, pronamide, and terbacil) were evaluated for control of sedge (*Carex* spp.) and beargrass (*Xerophyllum tenax* [Pursh] Nutt.) to aid establishment of newly planted seedlings of western white pine (*Pinus monticola* Dougl. ex D. Don), noble fir (*Abies procera* Rehd.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), and Shasta red fir (*Abies magnifica* Murr. var. *shastensis* Lemm.). All trials were conducted on upper-slope sites ranging from 3300 to 4600 ft (1000 to 1400 m) in the Cascade Range. Various rates and mixtures of herbicide were compared as both preplanting and postplanting sprays in three independent studies.

After 3 years, greatest gains in conifer survival were associated with glyphosate sprays. In three widely separated localities, survival of white pine associated with best glyphosate treatments was 80, 77, and 30 percent compared to 40, 34, and 4 percent for untreated checks, respectively. Among other conifers, corresponding contrasts in survival between glyphosate treatment and untreated checks were: 56 versus 12 percent for noble fir, 30 versus 14 percent for Engelmann spruce, and 14 versus 0 percent for Shasta red fir.

Similar survival increases were also consistently achieved with atrazine + dalapon mixtures. Most successful applications of mixture produced 3-year survival of 62, 77, and 14 percent for white pine at the same three localities above. Survival of other conifers resulting from best atrazine + dalapon treatments was: 33 percent for noble fir, 46 percent for Engelmann spruce, and 14 percent for Shasta red fir.

Preplanting sprays of glyphosate and atrazine + dalapon proved generally, but not always, superior to postplanting sprays for enhancing survival of conifers.

Introduction

Upper-slope coniferous forests occupy an irregular belt paralleling the crest of the Cascade Range. These subalpine forests closely conform to the cool, moist transition zone separating lower-elevation temperate forests to the west and more arid forest types eastward (Franklin and Dyrness 1973). Reforesting upper slopes concurrent with orderly timber harvest presents new challenges, and silvicultural practices adapted to Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) at lower elevations apply only generally. A wider array of management options and species choices is needed for upper slopes.

As elevations increase in subalpine stands, Douglas-fir is replaced by other conifers. Typically, dominant species include Pacific silver fir (*Abies amabilis* Dougl. ex Forbes), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), noble fir (*Abies procera* Rehd.), and Shasta red fir (*A. magnifica* Murr. var. *shastensis* Lemm.). When harvested, such stands may regenerate unsatisfactorily despite intensive reforestation efforts. To survive, newly planted conifers must withstand extremes of temperature and also moisture stress, which is exacerbated by established plant competitors. Sites supporting dense cover of sedge (*Carex* spp.)— particularly long stolon sedge (*C. pensylvanica* Lam.)— and beargrass (*Xerophyllum tenax* [Pursh] Nutt.) appear especially prone to unacceptable seedling mortality and plantation failure.

Herbicides have proved useful for preparing conifer reforestation sites in herbaceous cover. Most studies, however, have concerned conifer crop species either unadapted or only marginally adapted to upper-slope forests of the Cascade Range (Crouch 1979; Dimock and Collard 1981; Eckert 1979; Gratkowski et al. 1979; Heidmann 1969, 1970; Newton 1974; and Stewart and Beebe 1974). Moreover, weed species targeted for control in other studies have been chiefly grasses (Gramineae) and broad-leaved forbs. Little is known about control of either sedges (Cyperaceae) or beargrass (Liliaceae) in forestry applications.

I describe three studies aimed at evaluating the potential of nine herbicides for use in planting-site preparation with four conifer species. All studies were begun in 1977 and monitored for 3 years.

Study Areas

A separate study was conducted on each of three ranger districts: Mount Adams (Gifford Pinchot National Forest), McKenzie (Willamette National Forest), and Prospect (Rogue River National Forest). The northernmost and intermediate locations (Mount Adams and McKenzie) fall within the *Abies amabilis* zone as described by Franklin and Dyrness (1973); the southernmost location (Prospect) falls within the *Abies magnifica shastensis* zone. Most prevalent soils at Mount Adams range from gravelly sandy loams to silt loams derived from varying combinations of pumice, basalt, and andesite. To the southward occur increasing deposits of pyroclastic rocks (tuffs, breccias, and agglomerates) that weather to silty clay and silty clay loams mixed with stonier and coarser soils derived from basaltic and andesitic bedrock. Topography on all districts is bench-like or mountainous with level to steeply sloping ground. Mean annual precipitation near the study areas is: 100 in (254 cm) at Mount Adams, 70 in (179 cm) at McKenzie, and 42 in (107 cm) at Prospect. Mean precipitation during June through August for the same locations is: 4.7 in (11.9 cm) at Mount Adams, 4.2 in (10.6 cm) at McKenzie, and 2.5 in (6.4 cm) at Prospect.

Site elevations of individual study blocks (three per district) averaged about 4000 ft (1220 m), but ranged from as low as 3300 ft (1000 m) at Mount Adams to as high as 4600 ft (1400 m) at Prospect (fig. 1). History of forest disturbance differed somewhat both within and between district locations. At McKenzie, all three blocks were sited within ½ mile (0.8 km) of one another. Slash on each had been burned broadcast after clear-cutting about 8 years before study initiation. Failing to regenerate naturally, each site supported a heavy cover of beargrass interspersed with sedge (fig. 2). Up to 12 miles (19.2 km) separated different block sites at Mount Adams and Prospect. Slash had been burned broadcast after recent clear-cutting on only one site at Mount Adams, and had been piled and burned on all sites at Prospect. Sedge was well represented at all district locations, but beargrass was sparse at Mount Adams and totally absent at Prospect. Only scattered advance regeneration of conifers had occurred at any location (fig. 3). Dominant species before harvest had been primarily noble fir at McKenzie, Pacific silver and noble fir at Mount Adams, and Shasta red fir at Prospect.

Figure 1.—The nine study blocks.

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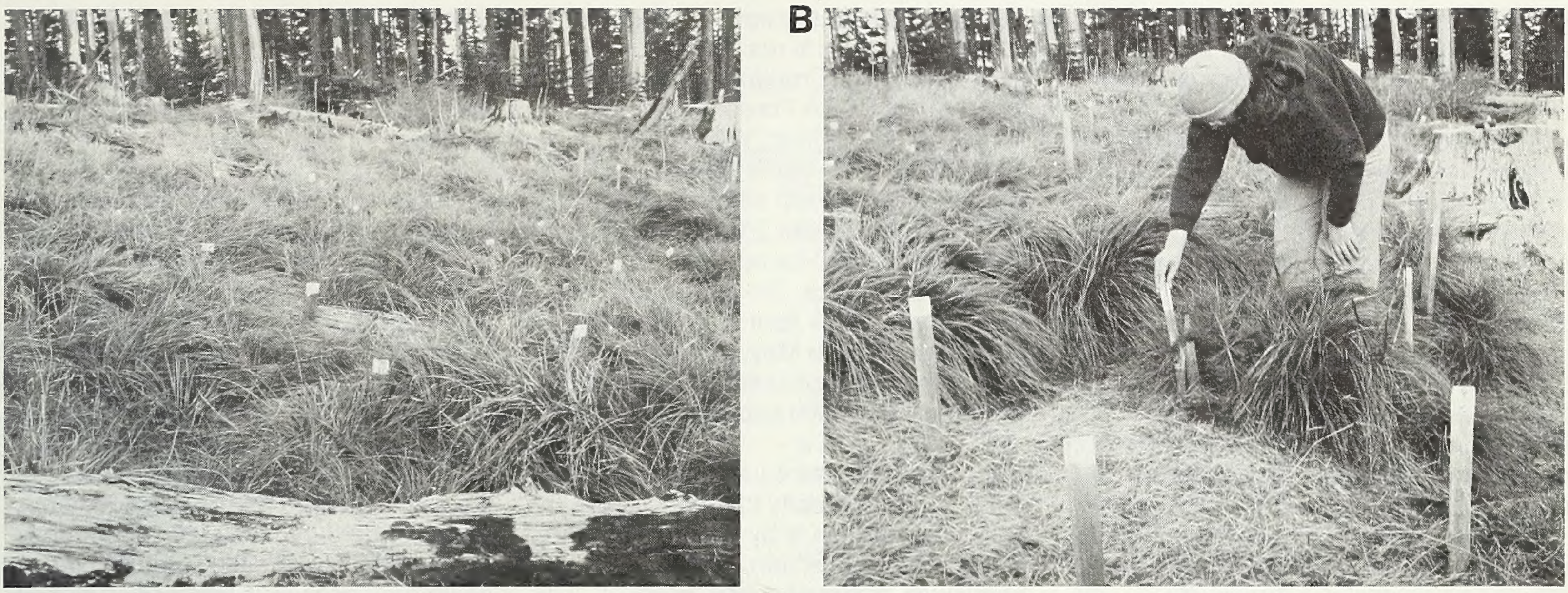

Figure 2.—(**A**) Canopy coverage of beargrass ranged up to 90 percent at McKenzie. (**B**) Gaps between beargrass clumps were dominated by a continuous mat of sedge, as shown in foreground.

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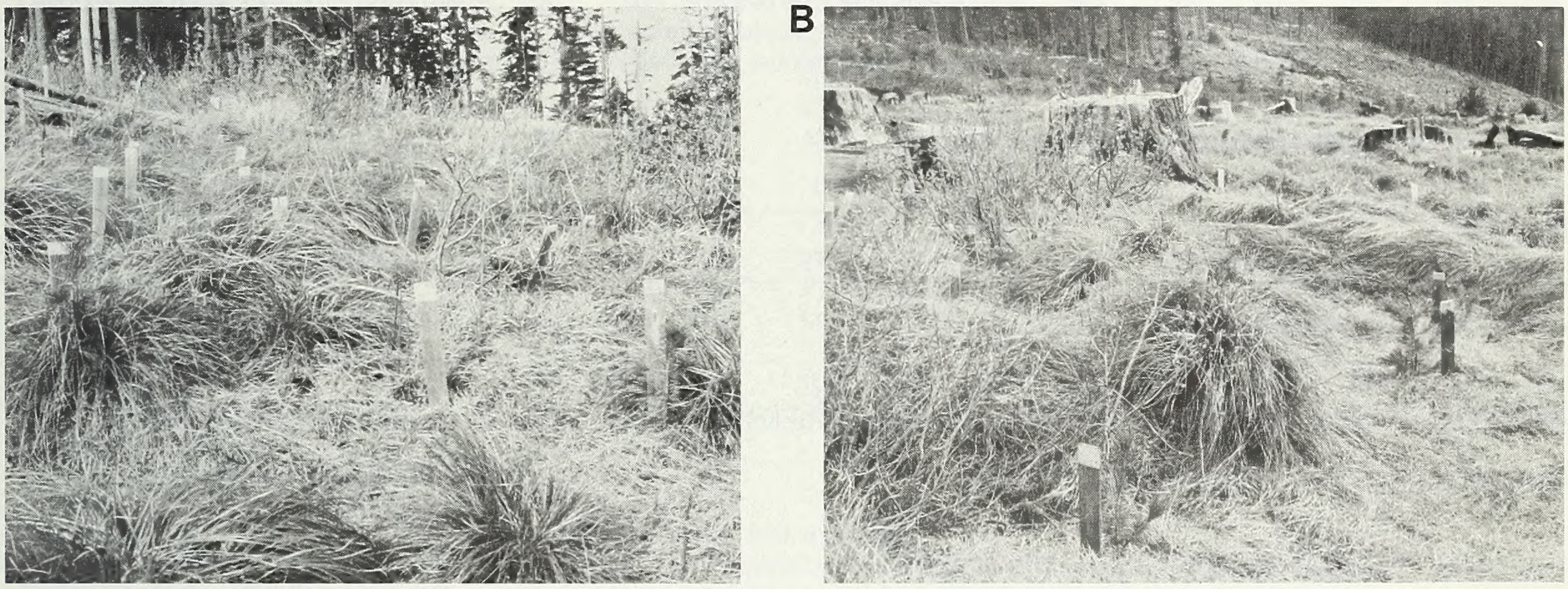

Figure 3.—(**A**) The predominant sedge-beargrass community at McKenzie proliferated from plants established under the preharvest forest overstory. Only scattered shrubs and (**B**) occasional naturally regenerated conifers were present.

Materials and Methods

Experimental design was identical on every district, and two conifer species were tested per study. Western white pine (*Pinus monticola* Dougl. ex D. Don) was common to all three tests, but a different second species was used in each: noble fir at McKenzie; Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) at Mount Adams; and Shasta red fir at Prospect. Hence, every district supported an intact split-plot (two species as sub-plots), randomized complete-block experiment replicated in 3 blocks. Each block contained 20 treatments (herbicides and rates) and 2 application times (preplanting and postplanting) randomly allocated to each of 40 square 1/100-acre (1/250-ha) main plots. Fifteen pine and 15 fir or spruce seedlings were planted on each plot in 6 rows of alternating species with 5 seedlings per row. Untreated buffers 10 ft (3 m) wide separated individual plots.

The USDA Forest Service nursery at Dorena, Oregon, provided all western white pine planting stock from a single source with general resistance to white pine blister rust (*Cronartium ribicola* Fisch.). The USDA Forest Service nursery at Wind River, Washington, provided all other stock grown from sources local to each study area. Class of planting stock was 2-0 for pine and Shasta red fir; 3-0 for noble fir and Engelmann spruce. Stock was lifted in late winter or early spring, stored at 2°C, and planted in late May. Where possible, the same worker planted all seedlings of one species in each experimental block.

Nine herbicides were used in each study (table 1). Both toxicity to herbaceous plants and tolerance by conifers were considered in selecting candidate herbicides, rates, and mixtures. Preplanting applications were made in mid-May and postplanting applications in early June—about 10 days, respectively, before and after tree planting. All herbicides were sprayed broadcast by backpack equipment at specified rates of active ingredient (ai) in water carriers at volumes of 200 gal/acre (1870 liter/ha). No attempt was made to protect tree seedlings from postplanting herbicide sprays.

Control of sedge (all locations) and beargrass (McKenzie) was rated in mid-summer; survival of conifers in early fall. Changes in species cover, visually estimated to the nearest 10 percent between plots and adjacent buffers, were used to calculate percentage control. Analysis of variance was used to test treatment response in separate years, and multiple comparisons were made by the FLSD method as recommended by Carmer and Swanson (1971). Primary analysis dealt with each study separately; secondary analysis combined all studies. Results of all studies were monitored for 3 years, but one block of treatments was lost in the 3d year (1979) at both Mount Adams and Prospect when some plots were inadvertently included in machine-scarification projects.

Table 1—Herbicides applied to sedge and beargrass

Common name	Chemical name	Formulation
Asulam	methyl sulfanilylcarbamate	Liquid, 3.34 lb ai/gal as sodium salt
Atrazine	2-chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine	80% wettable powder
Bromacil	5-bromo-3-*sec*-butyl-6-methyluracil	Liquid, 2 lb ai/gal as lithium salt
Cyanazine	2-[[4-chloro-6-(ethylamino)-*s*-triazin-2-yl] amino]-2-methylpropionitrile	80% wettable powder
Dalapon	2,2-dichloropropionic acid	84.5% soluble powder as sodium and magnesium salts
Glyphosate	*N*-(phosphonomethyl) glycine	Liquid, 4 lb ai/gal as isopropylamine salt
Hexazinone	3-cyclohexyl-6-(dimethylamino)-1 methyl-1,3,5-triazine-2,4(1*H*, 3*H*)-dione	90% soluble powder
Pronamide	3,5-dichloro (*N*-1, 1-dimethyl-2-propynyl) benzamide	50% wettable powder
Terbacil	3-*tert*-butyl-5-chloro-6-methyluracil	80% wettable powder

Results

Table 2—Control of sedge and beargrass at McKenzie after preplanting and postplanting herbicide sprays

Treatment (Rate in lb ai/acre)[1]		1977				1978				1979			
		Sedge		Beargrass		Sedge		Beargrass		Sedge		Beargrass	
		Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant
		Percent[2]											
Untreated check	(−)	0	0	0	0	0	0	0	0	0	0	0	0
Asulam	(5)	0	0	0	0	0	0	0	0	0	0	0	0
Atrazine	(4)	23	50	17	30	0	3	13	27	0	0	0	3
Atrazine + dalapon	(3+6)	87	83	23	27	25	23	30	27	7	10	0	7
Atrazine + dalapon	(4+8)	85	83	30	30	35	33	33	40	20	10	10	3
Atrazine + dalapon	(5+10)	90	97	30	43	47	45	43	40	27	17	27	7
Bromacil	(5)	73	73	53	47	3	3	53	40	7	13	40	33
Cyanazine + atrazine	(4+2)	30	43	27	33	0	3	37	23	3	0	0	0
Dalapon	(8)	77	77	30	20	10	23	27	27	3	7	7	0
Glyphosate	(2)	100	100	7	17	53	30	20	20	10	37	0	0
Glyphosate	(4)	100	97	30	23	90	63	50	37	63	37	23	17
Hexazinone	(1)	47	57	33	23	0	0	30	27	0	0	0	0
Hexazinone	(2)	70	77	50	40	0	10	37	40	0	7	0	7
Hexazinone	(3)	77	87	50	43	25	17	50	40	10	17	23	27
Hexazinone	(4)	87	87	53	40	20	47	47	47	13	27	13	17
Pronamide	(2)	0	0	0	0	0	0	0	0	0	3	0	0
Pronamide	(4)	3	0	0	0	0	0	0	0	0	0	0	0
Terbacil	(2)	47	37	30	27	0	0	20	33	0	0	0	3
Terbacil	(4)	60	53	47	47	20	10	37	40	0	3	0	0
Terbacil	(6)	83	70	47	53	17	7	47	40	20	13	13	3
LSD (P = 0.05)		20	20	16	16	23	23	15	15	17	17	15	15
LSD (P = 0.01)		26	26	22	22	31	31	20	20	23	23	20	20

[1] 1 lb/acre = 1.12 kg/ha.
[2] Values are means based on three replicates.

McKenzie

Sedge control.—With exception of asulam and pronamide, all herbicides significantly reduced sedge the 1st year (table 2). Glyphosate was clearly most effective, providing almost total initial control. Moreover, control with this herbicide persisted longer than that with any other. The preplanting application of glyphosate at 4 lb/acre[1] was still providing 63-percent sedge control through the 3d year. Atrazine + dalapon mixtures also gave good to excellent initial results at all rates used, but visible persistence of effect averaged less than with glyphosate. Atrazine used alone affected sedge only slightly, but dalapon alone gave moderately good control the 1st year. Dalapon probably contributed most to effectiveness of the atrazine + dalapon mixtures. A combination of cyanazine and atrazine performed similarly to atrazine alone, and resulted in light to moderate control with no effect persisting past the 1st year. Bromacil, hexazinone, and terbacil controlled sedge well initially at all except the lowest rates, but control with bromacil did not persist. Duration of control was short with terbacil, and only moderate with one high rate of hexazinone.

[1] 1 lb/acre = 1.12 kg/ha.

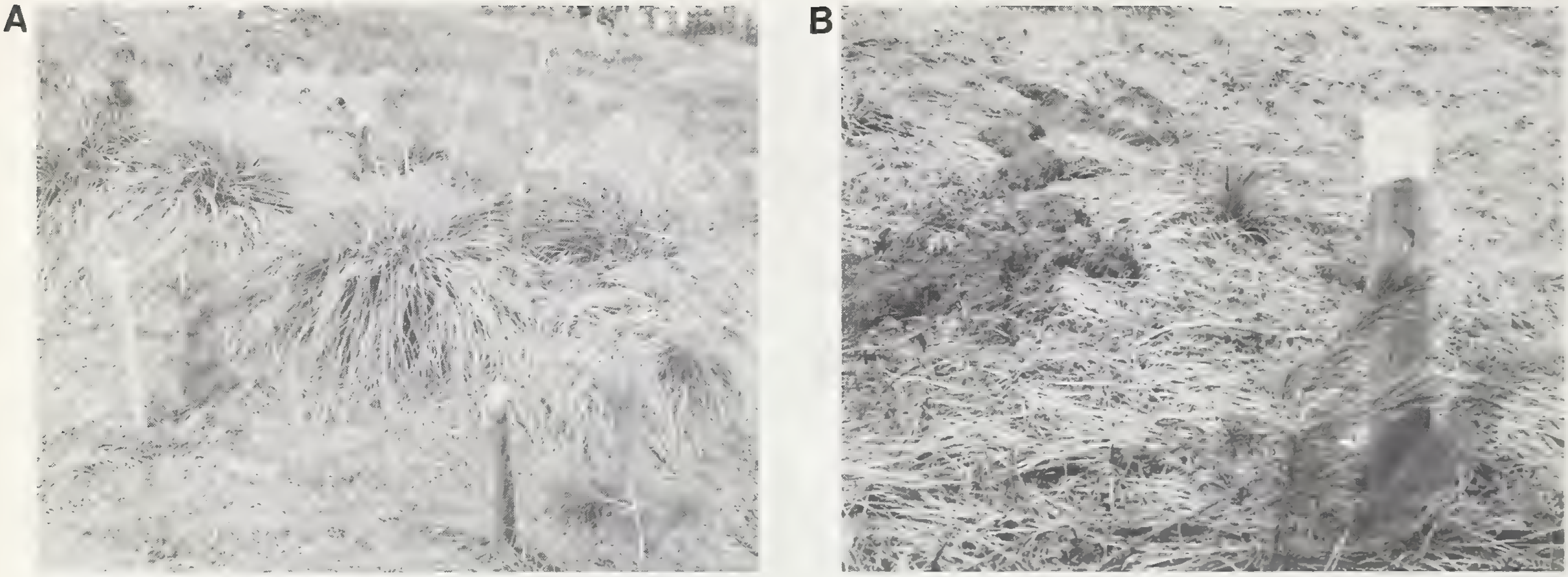

Figure 4.—(**A**) Most surviving western white pine commenced vigorous growth after the third growing season, but some additional mortality seems likely. (**B**) Damage by pocket gophers (*Thomomys monticola mazama* Merriam) was often associated with conifer losses at McKenzie, and will probably continue.

Beargrass control.—First-year control of beargrass did not exceed 53 percent for any herbicide, and reached that level only with bromacil, hexazinone, and terbacil (table 2). Moderate control persisted for 3 years with bromacil, and for 2 years with hexazinone and terbacil. Glyphosate had almost no effect on beargrass the 1st year at a rate of 2 lb/acre and only a slight effect at 4 lb/acre. Interestingly, at the higher rate, control increased from light the 1st year to moderate the 2d. Light 1st-year control was also attained with atrazine, cyanazine + atrazine, and dalapon, and persisted undiminished through the 2d year. Control of beargrass with combined atrazine and dalapon consistently bordered between light and moderate in both 1st and 2d years at all rates applied. Asulam and pronamide appeared totally ineffective on beargrass.

Conifer survival.—Seventy-four percent of untreated western white pine seedlings survived the first growing season, but only 40 percent were alive by the end of the third (fig. 4). Untreated noble fir survived less well, and declined from 44 percent alive the 1st year to 18 percent the 3d.

During 1977, no herbicide produced a significant gain in white pine survival, and only glyphosate benefited noble fir (table 3). The gain for noble fir, however, was substantial. Both low and high preplanting rates of glyphosate produced 71-percent survival versus 37 percent for the untreated check. This 34-percent margin widened to a mean for both rates of 40 percent (52 versus 12 percent) by the 3d year. Though benefits of glyphosate were not significant for white pine in 1977, they became so in 1978, and were associated with both preplanting and postplanting applications in 1979. The greatest survival gain accrued from post-planting treatment at 2 lb/acre that significantly doubled pine survival after 3 years—i.e., 80 percent for glyphosate treatment versus 40 percent for the untreated check.

Table 3—Survival of western white pine and noble fir at McKenzie after preplanting and postplanting herbicide sprays

Treatment (Rate in lb ai/acre)[1]		1977				1978				1979			
		White pine		Noble fir		White pine		Noble fir		White pine		Noble fir	
		Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant
		Percent[2]											
Untreated check	(−)	78	71	37	51	58	49	20	29	40	40	12	24
Asulam	(5)	54†	62	27	22†	34†	56	18	15	34	51	11	15
Atrazine	(4)	62	69	24	40	55	65	12	23	44	57	7	20
Atrazine + dalapon	(3+6)	69	76	44	49	56	62	30	38	54	58	28	32
Atrazine + dalapon	(4+8)	68	76	47	42	56	58	33	36	49	58	27	33
Atrazine + dalapon	(5+10)	80	49	50	22†	67	40	21	16	62*	35	14	9
Bromacil	(5)	33††	47†	20	18††	27††	20††	7	11	16†	20†	4	7
Cyanazine + atrazine	(4+2)	78	49	44	27†	55	44	22	18	49	42	18	16
Dalapon	(8)	74	71	40	47	66	57	33	18	60*	52	33*	13
Glyphosate	(2)	74	93	71**	72	67	80**	58**	42	64*	80**	56**	33
Glyphosate	(4)	59	78	71**	64	59	71*	53**	49	56	71**	47**	40
Hexazinone	(1)	47††	58	31	27†	35†	42	13	16	29	40	11	9
Hexazinone	(2)	49†	50	27	27†	40	35	22	9	31	34	22	9
Hexazinone	(3)	41††	28††	30	18††	33†	14††	18	11	21	9††	11	9
Hexazinone	(4)	38††	33††	13†	27†	31†	14††	11	13	29	9††	7	9
Pronamide	(2)	82	55	40	29	70	47	22	16	64*	38	22	9
Pronamide	(4)	82	51	44	27†	64	44	35	20	53	34	24	13
Terbacil	(2)	58	53	13†	31	48	42	0	18	44	29	0	16
Terbacil	(4)	49†	43†	7††	15††	42	23†	2	2†	38	21	2	0†
Terbacil	(6)	29††	38††	5††	13††	11††	32	0	4†	9††	29	0	4†
LSD (P=0.05)		23	23	23	23	21	21	21	21	20	20	20	20
LSD (P=0.01)		30	30	30	30	28	28	28	28	27	27	27	27

[1] 1 lb/acre = 1.12 kg/ha.
[2] Values are means based on 3 replicates of 15 trees each. Means followed by * or ** exceed untreated checks by $P<0.05$ and $P<0.01$, respectively; means followed by † or †† fall below untreated checks by $P<0.05$ and $P<0.01$, respectively.

Three other preplanting treatments produced significant survival gains for white pine by 1979: atrazine + dalapon (5 + 10 lb/acre), dalapon (8 lb/acre), and pronamide (2 lb/acre). Preplanting application of dalapon also benefited noble fir. Except for the highest post-planting rate (5 + 10 lb/acre), atrazine + dalapon mixtures at other rates and application times consistently tended to improve white pine survival — but not significantly. The two lower rates (3 + 6 and 4 + 8 lb/acre) were probably also beneficial for noble fir. Dalapon alone at 8 lb/acre appeared possibly harmful only as a postplanting spray to noble fir. The significant benefit of pronamide at 2 lb/acre for white pine was surprising in view of its lack of visible effect on sedge and beargrass. Postplanting applications of this herbicide appeared damaging to both pine and fir in 1977, but this effect became less evident by 1979.

Asulam significantly reduced 1st-year survival of both white pine and noble fir after preplanting and postplanting applications, respectively. By the end of the third season, however, effects were mostly neutral. Both atrazine and cyanazine + atrazine had a similarly neutral effect on conifer survival over time, though postplanting use of the combination tended to depress survival of both species the 1st year. Bromacil clearly reduced pine and fir survival throughout the 3-year period, and preplanting application was no less toxic than postplanting. With minor exceptions, conifers treated with hexazinone and terbacil, regardless of application time, survived less well than untreated checks —and mortality generally increased with increasing dosage rate.

Table 4—Control of sedge at Mount Adams after preplanting and postplanting herbicide sprays

Treatment (Rate in lb ai/acre)[1]		1977 Pre-plant	1977 Post-plant	1978 Pre-plant	1978 Post-plant	1979 Pre-plant	1979 Post-plant
		Percent [2]					
Untreated check	(−)	0	0	0	0	0	0
Asulam	(5)	0	0	0	0	0	0
Atrazine	(4)	0	10	0	0	0	0
Atrazine + dalapon	(3+6)	83	70	57	33	55	40
Atrazine + dalapon	(4+8)	100	90	75	75	60	55
Atrazine + dalapon	(5+10)	100	73	93	83	60	70
Bromacil	(5)	73	50	55	20	95	50
Cyanazine + atrazine	(4+2)	10	27	5	0	15	0
Dalapon	(8)	47	50	37	33	40	35
Glyphosate	(2)	83	100	50	47	60	60
Glyphosate	(4)	100	100	63	75	85	70
Hexazinone	(1)	27	5	10	0	5	0
Hexazinone	(2)	60	37	40	10	40	15
Hexazinone	(3)	73	30	47	40	65	40
Hexazinone	(4)	83	43	77	40	60	50
Pronamide	(2)	0	0	0	0	0	0
Pronamide	(4)	0	3	0	0	0	0
Terbacil	(2)	30	7	7	3	10	0
Terbacil	(4)	57	20	60	20	60	25
Terbacil	(6)	60	25	60	43	60	50
LSD (P=0.05)		37	37	40	40	47	47
LSD (P=0.01)		49	49	53	53	64	64

[1] 1 lb/acre = 1.12 kg/ha.
[2] Values in 1977 and 1978 are means based on 3 replicates; values in 1979 on 2 replicates.

Mount Adams

Sedge control.—Glyphosate provided total initial control of sedge for all applications except preplanting spray at 2 lb/acre (table 4). Significant control persisted through the 3d year at levels of 60 to 85 percent. During the 1st year, applications of atrazine + dalapon also produced 100-percent control at preplanting rates of 4 + 8 and 5 + 10 lb/acre, and gave good to excellent control at the preplanting rate of 3 + 6 lb/acre, as well as at all postplanting rates. Significant sedge reductions likewise persisted through the 3d year, when control ranged from 40 to 70 percent. Dalapon alone at 8 lb/acre controlled sedge moderately in all years, but significantly in only the 1st. Atrazine at 4 lb/acre was almost totally ineffective—as also were asulam and pronamide. Despite some visible, but not significant, 1st-year control, cyanazine + atrazine failed to reduce sedge. Control with bromacil was both effective and extremely persistent, though the 95-percent 3d-year control with preplanting application reflects loss of the replicate in which bromacil controlled sedge least. Higher rates of hexazinone and terbacil also significantly controlled sedge for 3 years, especially in preplanting applications.

All preplanting treatments combined produced significantly greater sedge control each year than all postplanting treatments. Because of nearly 5 weeks between spraying times in this test, activity of most preplanting sprays was likely enhanced by higher precipitation shortly after application.

Table 5—Survival of western white pine and Engelmann spruce at Mount Adams after preplanting and postplanting herbicide sprays

Treatment (Rate in lb ai/acre)[1]		1977				1978				1979			
		White pine		Engelmann spruce		White pine		Engelmann spruce		White pine		Engelmann spruce	
		Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant
		Percent[2]											
Untreated check	(−)	73	80	25	35	53	69	16	29	34	43	14	14
Asulam	(5)	71	75	27	22	55	51	20	16	43	40	16	10
Atrazine	(4)	79	73	33	25	67	64	24	23	54	54	16	27
Atrazine + dalapon	(3+6)	89	79	40	47	82*	74	32	38	76**	57	40	46*
Atrazine + dalapon	(4+8)	82	84	31	33	78*	73	31	20	77**	46	30	16
Atrazine + dalapon	(5+10)	82	62	44	27	62	53	31	27	50	37	37	26
Bromacil	(5)	18††	42††	14	2††	9††	25††	9	0†	4†	14†	0	0
Cyanazine + atrazine	(4+2)	78	89	27	47	62	66	20	42	50	60	27	33
Dalapon	(8)	63	76	36	27	49	55	24	9	23	36	24	6
Glyphosate	(2)	89	25††	36	22	84*	25††	24	20	77**	37	20	26
Glyphosate	(4)	91	11††	53*	27	87**	11††	38	22	76**	14†	30	24
Hexazinone	(1)	80	67	36	47	71	58	31	38	64*	47	27	30
Hexazinone	(2)	47†	47††	27	38	45	38†	20	33	47	36	20	30
Hexazinone	(3)	31††	36††	38	29	22†	27††	29	20	14	20	30	20
Hexazinone	(4)	33††	36††	20	22	27†	22††	13	18	14	14†	14	20
Pronamide	(2)	55	87	15	42	45	58	13	27	44	36	16	10
Pronamide	(4)	62	84	25	33	47	62	18	18	26	34	20	14
Terbacil	(2)	49†	73	18	9†	31	44†	13	0†	13	37	10	0
Terbacil	(4)	40††	45††	11	24	29†	27††	4	4†	20	16	4	0
Terbacil	(6)	13††	31††	11	7†	2††	7††	2	2†	4†	4††	0	0
LSD (P=0.05)		22	22	22	22	24	24	24	24	29	29	29	29
LSD (P=0.01)		30	30	30	30	32	32	32	32	39	39	39	39

[1] 1 lb/acre = 1.12 kg/ha.

[2] Values in 1977 and 1978 are means based on 3 replicates of 15 trees each; values in 1979 on 2 replicates. Means followed by * or ** exceed untreated checks by $P<0.05$ and $P<0.01$, respectively; means followed by † or †† fall below untreated checks by $P<0.05$ and $P<0.01$, respectively.

Conifer survival.—White pine survival on untreated plots at Mount Adams, much like that at McKenzie, dropped from 76 percent the first season to 38 percent the third. Engelmann spruce survived poorly—only 30 percent the 1st year, declining to 14 percent by the 3d. Preplanting sprays of glyphosate at both 2 and 4 lb/acre significantly increased white pine survival over untreated checks by the 2d and 3d years (table 5). Postplanting sprays of the same herbicide, however, proved decidedly harmful—contradictory to results at McKenzie. Engelmann spruce strongly benefited in the 1st year from preplanting application of glyphosate at 4 lb/acre, but the significant gain was ephemeral. For pine, patterns of gain with preplanting sprays of atrazine + dalapon at 3 + 6 and 4 + 8 lb/acre were nearly identical to those attained with glyphosate. Postplanting atrazine + dalapon spray at the lightest rate also significantly increased survival of Engelmann spruce. Preplanting spray of hexazinone at 1 lb/acre initially suggested some possible benefit for pine, and ultimately became significantly beneficial after 3 years. Other applications of hexazinone resulted in seedling survival generally equal to or less than untreated checks.

Among remaining herbicides, cyanazine + atrazine proved the most promising for enhancing conifer survival. Though the combination produced no significant gains, both preplanting and postplanting sprays may have improved survival of white pine and Engelmann spruce after three seasons. Atrazine by itself also produced no conclusive gains, but survival of white pine at 3 years may have benefited moderately. Asulam, dalapon, and pronamide neither increased nor reduced survival of pine and spruce in any consistent way. Bromacil and terbacil produced consistently negative responses with both species.

Table 6—Control of sedge at Prospect after preplanting and postplanting herbicide sprays

Treatment (Rate in lb ai/acre)[1]		1977		1978		1979	
		Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant
		Percent [2]					
Untreated check	(−)	0	0	5	0	0	0
Asulam	(5)	3	0	0	9	0	0
Atrazine	(4)	40	53	4	13	6	8
Atrazine + dalapon	(3+6)	77	87	52	54	25	40
Atrazine + dalapon	(4+8)	83	90	77	66	68	60
Atrazine + dalapon	(5+10)	97	93	76	80	69	64
Bromacil	(5)	60	67	53	63	85	71
Cyanazine + atrazine	(4+2)	47	63	0	12	0	0
Dalapon	(8)	93	60	53	54	40	40
Glyphosate	(2)	90	90	65	61	72	28
Glyphosate	(4)	97	97	85	92	46	70
Hexazinone	(1)	53	47	20	4	34	0
Hexazinone	(2)	70	63	37	26	42	14
Hexazinone	(3)	77	83	83	34	59	41
Hexazinone	(4)	83	90	71	55	63	40
Pronamide	(2)	0	3	0	4	0	6
Pronamide	(4)	3	0	0	4	0	6
Terbacil	(2)	43	50	5	4	8	0
Terbacil	(4)	60	67	46	25	39	28
Terbacil	(6)	87	77	47	23	52	29
LSD (P=0.05)		24	24	29	29	42	42
LSD (P=0.01)		32	32	38	38	57	57

[1] 1 lb/acre = 1.12 kg/ha.
[2] Values in 1977 and 1978 are means based on 3 replicates; values in 1979 on 2 replicates.

Prospect

Sedge control.—As at McKenzie and Mount Adams, only asulam and pronamide failed to control sedge (table 6). Excellent to nearly total control was attained with glyphosate at rates of both 2 and 4 lb/acre, and significant control persisted through the 3d year for all but the lightest postplanting application rate. All rates of atrazine + dalapon gave good to excellent control initially, and only the lightest application of the mixture (3 + 6 lb/acre) did not control sedge significantly through the 3d year. Atrazine alone at 4 lb/acre reduced sedge moderately in 1977, but control did not persist. Dalapon alone at 8 lb/acre, however, provided appreciably better and far more lasting control. As at other study locations, sedge control with cyanazine + atrazine was similar to that attained with atrazine used alone. Highly persistent activity was evident with bromacil, which produced moderate control of sedge in 1st and 2d years, and even greater control in the 3d. This persistence agrees with a like result at Mount Adams, but contradicts the short-term control of sedge attained with bromacil at McKenzie. All rates of hexazinone and terbacil produced moderate to good sedge control the 1st year, and significant control carried over to the 3d year with higher rates of both herbicides.

Table 7—Survival of western white pine and Shasta red fir at Prospect after preplanting and postplanting herbicide sprays

Treatment (Rate in lb ai/acre)[1]		1977				1978				1979			
		White pine		Shasta fir		White pine		Shasta fir		White pine		Shasta fir	
		Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant
		Percent[2]											
Untreated check	(−)	27	33	5	18	9	9	2	0	10	4	0	0
Asulam	(5)	24	49	2	22	11	11	2	9	10	10	0	4
Atrazine	(4)	40	55	5	28	5	14	5	11	7	10	0	0
Atrazine + dalapon	(3+6)	60**	45	29*	11	13	9	20**	2	10	4	0	0
Atrazine + dalapon	(4+8)	49	57*	36*	44*	25**	13	18**	9	10	14	4	0
Atrazine + dalapon	(5+10)	29	49	27	24	13	7	16*	9	0	4	14**	6
Bromacil	(5)	2†	35	0	5	0	9	0	2	0	10	0	4
Cyanazine + atrazine	(4+2)	58*	44	23	23	18	14	7	15*	10	6	6	20**
Dalapon	(8)	44	38	27	9	11	15	5	2	6	13	0	0
Glyphosate	(2)	64**	55	49**	42*	27**	25**	24**	20**	24**	30**	4	14**
Glyphosate	(4)	60**	24	40**	34	29**	7	24**	13*	10	4	14**	6
Hexazinone	(1)	11	21	2	13	0	2	0	0	0	4	0	0
Hexazinone	(2)	12	18	5	11	2	7	0	4	4	0	0	0
Hexazinone	(3)	2†	27	11	18	2	9	2	11	4	10	0	7
Hexazinone	(4)	4	11	7	7	0	2	2	0	0	4	4	0
Pronamide	(2)	42	47	27	9	18	15	15*	2	14	16*	6	0
Pronamide	(4)	38	34	16	18	11	5	9	2	6	0	6	0
Terbacil	(2)	20	36	9	5	0	5	0	0	0	4	0	0
Terbacil	(4)	2†	40	0	0	2	5	0	0	0	0	0	0
Terbacil	(6)	4	18	2	0	0	2	0	0	0	0	0	0
LSD (P=0.05)		24	24	24	24	12	12	12	12	11	11	11	11
LSD (P=0.01)		32	32	32	32	16	16	16	16	14	14	14	14

[1] lb/acre = 1.12 kg/ha.

[2] Values in 1977 and 1978 are means based on 3 replicates of 15 trees each; values in 1979 on 2 replicates. Means followed by * or ** exceed untreated checks by $P<0.05$ and $P<0.01$, respectively; means followed by † fall below untreated checks by $P<0.05$.

Conifer survival.—Subfreezing temperatures occurred at Prospect during the 1st week of July in 1977, and planted conifers survived their 1st year poorly in consequence. Adverse effects were even more evident by the 2d year. Mean survival of untreated seedlings dropped from 30 to 9 percent for white pine and from 12 to 1 percent for Shasta fir by the end of 1978. Despite these heavy losses, some increases in survival were associated with herbicide treatment (table 7). Glyphosate proved most consistently beneficial for both pine and fir over the 3-year period. Substantial gains for both species during 1977 and 1978 were chiefly associated with preplanting sprays at rates of either 2 or 4 lb/acre. Postplanting sprays at the lower rate were also nearly as effective. By the end of 1979, either preplanting or postplanting applications at the rate of 2 lb/acre were still providing small but significant gains for pine. Several preplanting and postplanting applications of atrazine + dalapon similarly improved pine and fir survival in 1977, but significant gains in 1978 and 1979 stemmed only from preplanting sprays. A substantial 1st-year benefit to white pine from preplanting spray of cyanazine + atrazine proved only temporary, but postplanting spray of the same herbicide aided Shasta fir in the 2d and 3d years. Pronamide at 2 lb/acre also produced small gains for fir during the 2d year and pine during the 3d.

Among other treatments, atrazine at 4 lb/acre and dalapon at 8 lb/acre came closest to providing significant gains in 1977 with postplanting application to pine and preplanting application to fir, respectively. Though survival was 22 percent higher than untreated checks in each case, the advantages did not persist. Asulam appeared neither to increase nor reduce survival of either species in any year. With exception of a few generally neutral responses, bromacil, hexazinone, and terbacil consistently depressed survival of both conifer species below that of untreated checks.

Discussion

Study locations varied considerably in soil, climate, and vegetation. Trends common to all three studies, therefore, are useful for evaluating the consistency of results and broadening the base for inference. Pine was common as a crop species to all tests, but another conifer was unique to each. As survival and treatment response were similar for fir and spruce, all three studies were combined for gross comparison of treatments. This grouping provided nine survival replicates per treatment for pine, and a like number for fir and spruce combined. The number of replicates in each group declined to seven in 1979.

Greatest and most obvious survival gains were consistently associated with preplanting sprays of glyphosate (table 8). Among pine, differences between glyphosate treatments and untreated checks were significant each year for all but one preplanting comparison. Among fir and spruce, all corresponding comparisons, without exception, revealed significant gains. Though 2 lb/acre of glyphosate proved somewhat more effective with pine than 4 lb/acre, the opposite was true with fir + spruce. Partly because of poorer survival of fir + spruce compared to pine, gains for fir + spruce were proportionally greater than those for pine. Absolute percentage gains, however, were similar for both species groups. A significant survival benefit at 3 years for pine sprayed after planting with 2 lb/acre of glyphosate reflects a cumulative superiority of this treatment at McKenzie and Prospect (tables 3 and 7). Postplanting glyphosate sprays, nevertheless, were clearly toxic to pine at Mount Adams (table 5).

Applied before planting, combination sprays of atrazine and dalapon also significantly increased survival of both pine and fir + spruce (table 8). Gains were correspondingly less than those attained with glyphosate, but still highly practical. The rate of 3 + 6 lb/acre provided greatest success by the 3d year for both species groups. The two higher rates (4 + 8 and 5 + 10 lb/acre) generally tended to decline in effectiveness as dosages increased. Postplanting spray at the highest rate consistently reduced survival below that of untreated checks, but losses were not significant.

The significant increase in survival for white pine associated with preplanting application of pronamide at 2 lb/acre may or may not indicate a general benefit of treatment (table 8). This gain depends strongly on results attained with pronamide at McKenzie (table 3). Mode of action by pronamide, and also asulam, is through disruption of mitosis in meristematic plant tissue (Weed Science Society of America 1979). As neither herbicide visibly affected sedge or beargrass, the apparent benefit to pine from a preplanting pronamide spray is not readily explained. Possible impact upon soil organisms or upon allelopathic activity of target plants may be involved, and further research is warranted.

Except for asulam and pronamide, all herbicides controlled target species at least minimally. Two *s*-triazine compounds, atrazine and cyanazine, were associated with light initial control, short persistence of effect, and little or no toxicity to conifers. A third *s*-triazine, hexazinone, resulted in moderate to good initial control, moderate to long persistence of effect, but unacceptable toxicity to conifers at all but the lightest rate (1 lb/acre) of application. The two substituted uracils, terbacil and bromacil, provided control of target species, persistence of effect, and mortality of conifers similar to results attained with hexazinone. Triazines and uracils act in plants chiefly as inhibitors of photosynthesis; dalapon and glyphosate interfere with protein metabolism (Hoagland and Duke 1981, Whitesides 1981). Interestingly, the latter two herbicides were the ones in these tests most commonly associated with effective control of target vegetation coupled with enhancement of conifer survival.

Though control of beargrass was rated only at McKenzie, herbicides with the most visible impact—i.e., bromacil, hexazinone, and terbacil—were not the ones yielding greatest survival benefits for conifers. Rather, herbicides combining maximal activity on the sedge component of the sedge-beargrass community with minimal toxicity to conifers proved ultimately best. Even if attainable, a high degree of beargrass control may well be unnecessary if substantially improved survival of conifers is possible without it. Sedge is more shallowly rooted than beargrass, and, where the two species coexist, competes more directly in the rooting zone of newly planted seedlings. Measures that effectively mitigate effects of below-ground competition at shallower depths are more likely to forestall much conifer mortality that occurs soon after planting.

Both success of plantation establishment and subsequent stand development need be considered in species selection for upper slopes. Conifers in these studies are well adapted to the locations where tested. Western white pine on various sites consistently survived 2 to 3 times better than noble fir, Engelmann spruce, or Shasta red fir. Without treatment, however, survival of all species was ultimately disappointing after 3 years. Certain herbicides used for site preparation succeeded in substantially raising survival of all four species. Moreover, the gains achieved were of sufficient proportion or magnitude to bridge the gap between success and failure of conifer plantations in typical management situations.

Table 8—Survival of western white pine, noble fir, Engelmann spruce, and Shasta red fir at McKenzie, Mount Adams, and Prospect combined, after preplanting and postplanting herbicide sprays

Treatment (Rate in lb ai/acre)[1]		1977 White pine Pre-plant	1977 White pine Post-plant	1977 Fir + spruce Pre-plant	1977 Fir + spruce Post-plant	1978 White pine Pre-plant	1978 White pine Post-plant	1978 Fir + spruce Pre-plant	1978 Fir + spruce Post-plant	1979 White pine Pre-plant	1979 White pine Post-plant	1979 Fir + spruce Pre-plant	1979 Fir + spruce Post-plant
		Percent[2]											
Untreated check	(−)	59	61	22	35	40	42	13	19	30	31	9	14
Asulam	(5)	50	62	19	22	33	39	13	13	30	34	9	9
Atrazine	(4)	60	66	21	31	42	48	14	19	36	43	8	16
Atrazine + dalapon	(3 + 6)	73*	67	38*	36	50	48	27*	26	48*	42	23*	27
Atrazine + dalapon	(4 + 8)	66	72	38*	40	53	48	27*	22	46*	42	21	19
Atrazine + dalapon	(5 + 10)	64	53	40**	24	47	33	23	17	41	27	21	13
Bromacil	(5)	18††	41††	11	8††	12††	18††	5	4†	8††	15†	2	3
Cyanazine + atrazine	(4 + 2)	71	61	31	32	45	41	16	25	38	37	17	22
Dalapon	(8)	60	62	32	28	42	42	22	10	34	36	21	7
Glyphosate	(2)	76*	58	52**	42	59**	43	35**	27	56**	53**	31**	26
Glyphosate	(4)	70	38††	55**	42	58*	30	38**	28	49**	36	33**	26
Hexazinone	(1)	46	49	23	29	35	34	15	18	31	32	12	12
Hexazinone	(2)	36††	38††	20	25	29	27†	14	15	28	25	15	12
Hexazinone	(3)	25††	30††	26	22	19††	17††	16	14	14†	12††	13	12
Hexazinone	(4)	25††	27††	13	19†	19††	13††	9	10	16†	9††	8	10
Pronamide	(2)	60	63	27	27	44	40	17	15	44*	31	16	7
Pronamide	(4)	61	56	28	26	41	37	21	13	32	24	18	10
Terbacil	(2)	42†	54	13	15††	26†	30	4	6	23	24	3	7
Terbacil	(4)	30††	43††	6†	13††	24†	18††	2	2†	22	14†	2	0†
Terbacil	(6)	15††	29††	6†	7††	4††	14††	1	2†	5††	14†	0	2
LSD ($P = 0.05$)		14	14	14	14	14	14	14	14	14	14	14	14
LSD ($P = 0.01$)		18	18	18	18	19	19	19	19	19	19	19	19

[1] 1 lb/acre = 1.12 kg/ha.

[2] Values in 1977 and 1978 are means based on 9 replicates of 15 trees each; values in 1979 on 7 replicates. Means followed by * or ** exceed untreated checks by $P<0.05$ and $P<0.01$, respectively; means followed by † or †† fall below untreated checks by $P<0.05$ and $P<0.01$, respectively.

Research Application

Recent progress toward improving resistance of western white pine to blister rust demands reconsideration of this conifer for reforesting upper slopes. Moreover, its inherent capacity to tolerate freezing temperatures and moisture stress (Minore 1979) applies well to the normally frost-prone environments of sedge and beargrass communities. Relative resistance of Engelmann spruce to both frost and drought (Minore 1979) would likewise appear promising for exploitation. Plantations of noble fir and Shasta red fir, conifers frequently predominating in upper-slope stands, could also benefit by planting them mixed with hardier species. Mixed plantings would provide potential for more rapid and certain site occupancy, greater initial stand growth, and more efficient use of growing space.

Sprays of glyphosate or atrazine + dalapon mixtures can be used effectively for site preparation in plantations of western white pine, noble fir, Engelmann spruce, and Shasta red fir. The lowest rates tested—i.e., 2 lb ai/acre of glyphosate, or 3 + 6 lb ai/acre of atrazine + dalapon—provided gains in conifer survival similar to those achieved with higher rates. These herbicides and rates appear adequate for general use with the above species in aiding reforestation of upper-slope sites dominated by sedge and beargrass. Preplanting sprays averaged consistently more successful than postplanting sprays, but the latter produced equivalent and sometimes superior results in specific situations. In practice, performance of postplanting sprays could probably be enhanced by shielding conifers or directing spray applications to minimize contact with conifer foliage. High volume of water carrier used in herbicide treatments was aimed at enhancing thoroughness and uniformity of herbicide distribution. Lower volumes, normally used in practice, should differ little in effectiveness.

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Nine herbicides were compared for aiding establishment of four conifer species on upper-slope forest sites dominated by sedge and beargrass. Both glyphosate and a mixture of atrazine + dalapon produced substantial and consistent gains in survival of all four conifers after 3 years.

Keywords: Herbicides (-regeneration, site preparation (-regeneration, herbicide formulations, regeneration (stands), western white pine, Engelmann spruce, noble fir, Shasta red fir.

Pacific Northwest Forest and Range
Experiment Station
809 NE Sixth Avenue
Portland, Oregon 97232

GPO 994-536